

**CHAPTER II**  
**INDOOR AIR QUALITY**  
**RESULTS INTERPRETATION**

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II. RESULTS INTERPRETATION .....	3
A. Carbon Dioxide in Evaluating Ventilation in Buildings.....	3
B. Temperature .....	8
C. Relative Humidity .....	8
D. Microbial/Moisture Concerns .....	9
E. Products of Combustion (Carbon Monoxide and Particulate Matter).....	9
1. Carbon Monoxide .....	10
2. Particulate Matter.....	11
F. Volatile Organic Compounds .....	11
G. Other Environmental Issues .....	13
1. Carpeting.....	13
2. Asbestos-Containing Materials .....	13
3. Indoor Plants .....	14
4. Personal fans, ceiling fans, air purifiers and heaters.....	14
5. Accumulated Items .....	14
6. Kitchens/food.....	14
7. Ceiling Tile Systems .....	15
8. Upholstered Furniture/Pillows/Cushions, etc. ....	15
References .....	16

## **II. RESULTS INTERPRETATION**

### **A. Carbon Dioxide in Evaluating Ventilation in Buildings**

The Massachusetts Department of Public Health's (MDPH) Bureau of Environmental Health's (BEH) Indoor Air Quality (IAQ) Program examines IAQ conditions that may affect building occupants. The MDPH approach to resolving IAQ problems in schools and public buildings is generally two-fold: 1) improving ventilation to dilute and remove environmental pollutants and 2) reducing or eliminating exposure opportunities from materials that may be adversely affecting IAQ.

To examine the function of the ventilation system, IAQ staff take measurements for carbon dioxide, temperature and relative humidity. Carbon dioxide measurements are commonly used to assess the adequacy of ventilation within an indoor environment.

Carbon dioxide is an odorless, colorless gas. It is found naturally in the environment and is produced in the respiration process of living beings. Another source of carbon dioxide is the burning of fossil fuels. Carbon dioxide concentration in the atmosphere is approximately 250-600 parts per million (ppm) (Beard, 1982; NIOSH, 1987). It is important to note that for the first time in modern history, monthly atmospheric carbon dioxide levels are averaging *over* 400 ppm, based on figures released by the National Oceanic and Atmospheric Agency (NOAA) (<http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html>).

Carbon dioxide levels within an occupied building are a standard measure used to gauge the adequacy of a ventilation system. The indoor air of any building will have environmental pollutants. Human beings produce waste heat, moisture and carbon dioxide as by-products of the

respiration process. Equipment, plants, cleaning products or supplies normally found in any building can produce gases, vapors, fumes or dusts. If an occupied building has an adequately operating mechanical ventilation system, these normally-occurring environmental pollutants will be diluted and removed from the interior of the building. The introduction of fresh air through supply ventilation and removal of air through exhaust ventilation both increase the comfort of the occupants and serve to dilute the normally-occurring environmental pollutants.

If all or part of the ventilation system becomes non-functional, a buildup of normally-occurring environmental pollutants may occur, resulting in an increase in the discomfort of occupants including complaints about odors, irritation of the eyes or respiratory tract, sleepiness, and a feeling that the air is stale or stuffy. Typically, carbon dioxide levels above 800 ppm indicate a lack of air exchange in a building at the time of an assessment.

Minimum design ventilation rates are mandated by the Massachusetts State Building Code (MSBC). Until 2011, the minimum ventilation rate in Massachusetts was higher for both occupied office spaces and general classrooms, with similar requirements for other occupied spaces (BOCA, 1993). The current version of the MSBC, promulgated in 2011 by the State Board of Building Regulations and Standards (SBBRS), adopted the 2009 International Mechanical Code (IMC) to set minimum ventilation rates. **Please note that the MSBC is a minimum standard that is not health-based.** At lower rates of cubic feet per minute (cfm) per occupant of fresh air, carbon dioxide levels would be expected to rise significantly. A ventilation rate of 20 cfm per occupant of fresh air provides optimal air exchange resulting in carbon dioxide levels at or below 800 ppm in the indoor environment. MDPH recommends that carbon dioxide levels be maintained at or below this 800 ppm level. Most environmental and occupational health scientists involved with research on IAQ and health effects have documented

significant increases in IAQ complaints and/or health effects in schools, office buildings and other occupied spaces when carbon dioxide levels rise above 800 ppm (Sundell et al., 2011). A ventilation system should be on at all times when a room is occupied. During the cold weather season, providing adequate fresh air ventilation with open windows and maintaining the temperature in the comfort range is impractical. Therefore mechanical ventilation is usually required to provide adequate fresh air ventilation.

The MDPH chose a guideline of 800 ppm for publicly occupied buildings based on a variety of research studies. Several sources indicate that indoor air problems *are significantly reduced* at 800 ppm or less of carbon dioxide (ACGIH, 1998; Bright et al., 1992; Burge et al., 1990; Gold 1992; Hill, 1992; NIOSH, 1987; Norback, 1990; OSHA, 1994; Redlich, 1997; Rosenstock, 1996; SMACNA, 1998). Inadequate ventilation and/or elevated temperatures are major causes of complaints such as respiratory, eye, nose and throat irritation, lethargy and headaches.

Air levels of carbon dioxide that indicate IAQ may be a problem have also been established by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Above 1,000 ppm of carbon dioxide, ASHRAE recommends adjustment of the building's ventilation system (ASHRAE, 1989). In 1999, ASHRAE modified their standard to indicate that indoor air should contain no more than 700 ppm above the outdoor air concentration of carbon dioxide and this was reiterated in the 2001 standard (ASHRAE, 1999, ASHRAE 2001).

If indoor carbon dioxide levels are over 800 ppm, the MDPH recommends adjustment of the building's ventilation system to provide more fresh air. However, it is important to note that further reducing carbon dioxide levels below 800 ppm may not decrease IAQ complaints.

Sources of environmental pollutants indoors can often induce symptoms in exposed individuals regardless of the adequacy of the ventilation system. For example, an idling bus outside a building may have minimal effect on carbon dioxide levels but can be a source of carbon monoxide, particulates and odors via the ventilation system.

The Occupational Safety and Health Administration (OSHA) standard for carbon dioxide is 5,000 parts per million of air (ppm). Workers may be exposed to this level for 40 hours/week, based on a time-weighted average (OSHA, 1997). These levels are based on exposure of adult workers in an industrial environment where carbon dioxide is produced or used. Carbon dioxide can also be a hazard within enclosed areas with **no air supply**. These types of enclosed areas are known as confined spaces. Manholes, mines and sewer systems are examples of confined spaces. An ordinary building is not considered a confined space.

The main effect of carbon dioxide involves its ability to displace oxygen in the air in a confined space. As oxygen is inhaled, carbon dioxide levels build up in the confined space, with a decrease in oxygen content in the available air. This displacement of oxygen makes carbon dioxide a simple asphyxiant. At carbon dioxide levels of 30,000 ppm, severe headaches, diffuse sweating, and labored breathing have been reported. No **chronic** health effects are reported at air levels below 5,000 ppm.

For more information concerning the health effects of increasing levels of carbon dioxide and associated action levels, please see Table 1.

**Table 1: Carbon Dioxide Air Level Standards**

Carbon Dioxide Level	Health Effects	Standards or Use of Concentration	Reference
250-600 ppm	None	Concentrations in ambient air	Beard, R.R., 1982 NIOSH, 1987
600 ppm	None	Few indoor air complaints	ACGIH, 1998; Bright et al., 1992; Hill, 1992; NIOSH 1987
800 ppm	None	Used by MDPH as an indicator of ventilation adequacy in schools and public buildings.	Mendler, 2003 NCOSP, 1998; SMACNA, 1998; EA, 1997; Redlich, 1997; Rosenstock, 1996; OSHA, 1994; Gold, 1992; Burge et al., 1990; Norback, 1990 ; IDPH, Unknown
1,000 ppm	None	Used as an indicator of ventilation inadequacy for removal of odors from the interior of a building.	ASHRAE, 1989
950-1300 ppm*	None	Used as an indicator of ventilation inadequacy for removal of odors from the interior of a building.	ASHRAE, 1999
700 ppm (over background)	None	Used as an indicator of ventilation inadequacy for removal of odors from the interior of a building.	ASHRAE, 2001
5,000 ppm	No acute (short term) or chronic (long-term) health effects	Permissible Exposure Limit/Threshold Limit Value	ACGIH, 1999 OSHA, 1997
30,000 ppm	Severe headaches, diffuse sweating, and labored breathing	Short-term Exposure Limit	ACGIH, 1999 ACGIH, 1986

\* outdoor carbon dioxide measurement +700 ppm

## **B. Temperature**

The MDPH recommends that indoor air temperatures be maintained in a range of 70°F to 78°F to provide for the comfort of building occupants. Fluctuations of temperature in occupied spaces are common, even in a building with an adequate fresh air supply. It is difficult to control temperature and maintain comfort without a functioning ventilation system.

## **C. Relative Humidity**

The MDPH recommends a comfort range of 40 to 60 percent for indoor air relative humidity. Relative humidity levels in a building are expected to be higher in the summer due to outdoor conditions and lower during the winter months due to heating.

A sensation of dryness and irritation is common in a low relative humidity environment. Low relative humidity is a very common problem during the heating season in the northeast part of the United States.

Levels of relative humidity above 60 percent can contribute to feelings of heat-related discomfort. Higher humidity at a given temperature reduces the ability of the body to cool itself by sweating; “heat index” and “apparent temperature” are measures that take into account the impact of a combination of heat and humidity on how hot it feels. At a given indoor temperature, the addition of humid air increases occupant discomfort and may generate heat complaints. If moisture levels are decreased, the comfort of an individual increases. In addition, while temperature is mainly a comfort issue, relative humidity in excess of 70 percent for extended periods of time can provide an environment for mold and fungal growth (ASHRAE, 1989).



## **D. Microbial/Moisture Concerns**

For building materials to support mold growth, a source of water exposure is necessary. Identification and elimination of the source of water moistening building materials are necessary to control mold growth. The US EPA and the American Conference of Governmental Industrial Hygienists (ACGIH) recommend that porous materials be dried with fans and heating within 24 to 48 hours of becoming wet (US EPA, 2001; ACGIH, 1989). If porous materials are not dried within this time frame, mold growth may occur. Once mold has colonized porous materials, they are difficult to clean and should be removed and discarded.

## **E. Products of Combustion (Carbon Monoxide and Particulate Matter)**

Indoor air quality can be negatively influenced by the presence of respiratory irritants, such as products of combustion. The process of combustion produces a number of pollutants. Common combustion emissions include carbon monoxide, carbon dioxide, water vapor, and smoke (fine airborne particle material). Of these materials, exposure to carbon monoxide and particulate matter with a diameter of 2.5 micrometers ( $\mu\text{m}$ ) or less (PM<sub>2.5</sub>) can produce immediate, acute health effects upon exposure. To determine whether combustion products are present in the indoor environment, IAQ staff obtain measurements for carbon monoxide and PM<sub>2.5</sub>.

### *1. Carbon Monoxide*

Carbon monoxide is a by-product of the incomplete combustion of organic matter (e.g., gasoline, wood and tobacco). Exposure to carbon monoxide can produce immediate and acute health effects. Several air quality standards have been established to limit exposure to carbon monoxide and prevent symptoms from exposure to it. The MDPH established a corrective action level for carbon monoxide in ice skating rinks that use fossil-fueled ice resurfacing equipment. If an operator of an indoor ice rink measures a carbon monoxide level over 30 ppm, taken 20 minutes after resurfacing within a rink, that operator must take actions to reduce the carbon monoxide level (MDPH, 1997).

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has adopted the National Ambient Air Quality Standards (NAAQS) as one set of criteria for assessing IAQ and monitoring of fresh air introduced by HVAC systems (ASHRAE, 1989). The NAAQS are standards established by the US EPA to protect the public's health from six criteria pollutants, including carbon monoxide and particulate matter (US EPA, 2006). As recommended by ASHRAE, pollutant levels in fresh air introduced into a building should not exceed the NAAQS levels (ASHRAE, 1989). The NAAQS were adopted by reference in the Building Officials & Code Administrators (BOCA) National Mechanical Code of 1993 (BOCA, 1993), which is now an HVAC standard included in the Massachusetts State Building Code (SBBRS, 2011). According to the NAAQS, carbon monoxide levels in outdoor air should not exceed 9 ppm in an eight-hour average (US EPA, 2006).

*Carbon monoxide should not be present in a typical, indoor environment. If it is present, indoor carbon monoxide levels should be less than or equal to outdoor levels.*

## *2. Particulate Matter*

The US EPA has established NAAQS limits for exposure to particulate matter. Particulate matter includes airborne solids that can be irritating to the eyes, nose and throat. The NAAQS originally established exposure limits to PM with a diameter of 10  $\mu\text{m}$  or less (PM<sub>10</sub>). In 1997, US EPA established a more protective standard for fine airborne particulate matter with a diameter of 2.5  $\mu\text{m}$  or less (PM<sub>2.5</sub>). This more stringent PM<sub>2.5</sub> standard requires outdoor air particle levels be maintained below 35  $\mu\text{g}/\text{m}^3$  over a 24-hour average (US EPA, 2006). Although both the ASHRAE standard and BOCA Code adopted the PM<sub>10</sub> standard for evaluating air quality, MDPH uses the more protective PM<sub>2.5</sub> standard for evaluating airborne PM concentrations in the indoor environment.

Frequently, indoor air levels of particulates (including PM<sub>2.5</sub>) can be at higher levels than those measured outdoors. A number of activities that occur indoors and/or mechanical devices can generate particulate matter during normal operations. Sources of indoor airborne particulates may include but are not limited to particles generated during the operation of fan belts in the HVAC system; use of stoves and/or microwave ovens in kitchen areas; use of photocopiers, fax machines and computer printing devices; operation of an ordinary vacuum cleaner; and heavy foot traffic indoors.

## **F. Volatile Organic Compounds**

Indoor air concentrations can be greatly impacted by the use of products containing volatile organic compounds (VOCs). VOCs are carbon-containing substances that have the ability to evaporate at room temperature. Total volatile organic compounds (TVOCs) can result in eye and respiratory irritation if exposure occurs. For example, chemicals evaporating from a

paint can stored at room temperature would most likely contain VOCs. In an effort to identify materials that can potentially increase indoor VOC concentrations, IAQ staff examine rooms for products containing these respiratory irritants. If testing for TVOCs is warranted, outdoor air samples are taken for comparison to indoor levels.

Dry erase materials (DEM) e.g., dry erase marker and dry erase board cleaners may contain VOCs such as methyl isobutyl ketone, n-butyl acetate and butyl-cellusolve (Sanford, 1999). These chemicals can be irritating to the eyes, nose and throat.

Photocopiers can be sources of pollutants such as VOCs, ozone, heat and odors, particularly if the equipment is old and in frequent use. Both VOCs and ozone are respiratory irritants (Schmidt Etkin, 1992). Photocopiers should be kept in well ventilated rooms and should be located near windows or exhaust vents.

Hand sanitizer products may contain ethyl alcohol and/or isopropyl alcohol. These alcohols are highly volatile and may be irritating to the eyes and nose. Hand sanitizers may also contain fragrances to which some people may be sensitive.

Air deodorizers contain chemicals that can be irritating to the eyes, nose and throat of sensitive individuals. Many air fresheners contain 1,4-dichlorobenzene, a VOC which may cause a reduction in lung function (NIH, 2006). Furthermore, deodorizing agents do not remove materials causing odors, but rather mask odors that may be present in the area.

Cleaning products contain chemicals that can be irritating to the eyes, nose and throat of sensitive individuals. These products should be properly labeled. Consideration should also be given to working with building management to provide staff with compatible cleaning products and supplies to prevent any potential for adverse chemical interactions. A Material Safety Data Sheet (MSDS) should be available for all products used in a building.

## **G. Other Environmental Issues**

Other conditions that can affect IAQ are typically evaluated during BEH/IAQ assessments.

### *1. Carpeting*

The Institute of Inspection, Cleaning and Restoration Certification (IICRC) recommends that carpeting be cleaned annually (or semi-annually in soiled high traffic areas) (IICRC, 2012). The average lifespan of carpeting is approximately eleven years (Bishop, 2002) and plans should be made to replace worn carpeting before it becomes a source of particulates to the indoor environment. In addition, carpeting is generally not recommended in basement areas especially if exposed to chronic moisture. If asbestos-containing tile is located beneath carpets, care should be taken not to disturb tiles.

### *2. Asbestos-Containing Materials*

Intact asbestos-containing material (ACM) does not pose a health hazard. If damaged, ACM can be rendered friable and become aerosolized. Friable asbestos is a chronic (long-term) health hazard, but will not produce acute (short-term) health effects (e.g., headaches) typically associated with buildings believed to have IAQ problems. Where asbestos-containing materials are found damaged, these materials should be removed or remediated in a manner consistent with Massachusetts asbestos remediation laws (MDLI, 1993).

### *3. Indoor Plants*

Plants can be a source of pollen and mold, which can be respiratory irritants to some individuals. Plants should be properly maintained, over-watering of plants should be avoided and drip pans should be inspected periodically for mold growth and cleaned or replaced as necessary.

### *4. Personal fans, ceiling fans, air purifiers and heaters*

These items are often found to be dusty or have debris on their surfaces. Dust on these items can be reaerosolized and cause irritation or odors. In addition, air purifiers may have filters or other components that need to be cleaned and maintained so that they do not become a source of air pollution.

### *5. Accumulated Items*

In offices and classrooms, accumulations of items are often seen on floors, windowsills, tabletops, counters, bookcases and desks. These items, including papers, books, clothing and decorative/personal items, provide a source for dusts to accumulate and make it difficult for custodial staff to clean. Items should be stored in an organized fashion, in cabinets, on shelves or in plastic bins where possible, and should be relocated and/or be cleaned periodically to avoid excessive dust build up.

### *6. Kitchens/food*

Food should be kept in tightly-sealed containers to prevent attracting pests. Food preparation equipment should also be kept clean and free of debris.

### *7. Ceiling Tile Systems*

Ceiling tile systems should be intact. Missing/damaged tiles can allow dust/debris from above the ceiling tile system to enter occupied areas and be a source of eye and respiratory irritation. In addition, if the ceiling plenum is used as a return ventilation system, the tiles need to be intact to function as designed.

### *8. Upholstered Furniture/Pillows/Cushions, etc.*

Upholstered furniture, pillows, and cushions are covered with fabric that comes in contact with human skin. This type of contact can leave oils, perspiration, hair and skin cells. Dust mites feed upon human skin cells and excrete waste products that contain allergens. In addition, if relative humidity levels increase above 60 percent, dust mites tend to proliferate (US EPA, 1992). Frequent vacuuming of upholstered furniture is recommended to remove dust mites and other pollutants (Berry, 1994). It is also recommended that upholstered furniture (if present in schools), be professionally cleaned on an annual basis. If outdoor conditions or indoor activities (e.g., renovations) create an excessively dusty environment, cleaning frequency should be increased (every six months) (IICRC, 2000).

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